HIGH EFFICIENCY BOILER

FEASIBILITY ASSESSMENT, PHASE 2

Ontario Ministry of Housing
Technical Support Services Branch

Report of Investigation No. 35-22381

HIGH EFFICIENCY BOILER
FEASABILITY ASSESSMENT, PHASE 2

CASE BUILDING:
5 BELLEVUE CRESCENT, TORONTO

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February 1989

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EXECUTIVE SUMMARY

There is a potential for considerable energy savings, in buildings owned by the Ontario Ministry of Housing, through the installation of more efficient boilers. In a previous project done by ORTECH [1], energy savings and payback periods were estimated for several combinations of high efficiency, forced draft and existing boilers in a representative apartment building. It was recommended that investigations be extended to include other promising boilers, and to estimate life cycle costs of the various boiler configurations in [1].

The specific objectives of this project were:

- to estimate energy savings and payback periods due to the installation of hydronic heating systems consisting of combinations of existing boilers and modern atmospheric boilers (Weil-McLain LGB-10W).
- to estimate life cycle costs for configurations described in the previous project [1], and for the configurations using the boilers mentioned above;
- to provide recommendations for selecting a heating system based on the payback period and life cycle cost analysis.

Procedure

Energy Savings and Payback Periods for Hydronic Systems Utilizing a Modern Atmospheric Boiler

Details on the combinations of the new boilers and existing boilers that were evaluated are included in the table below.

Existing System			
input capacity (Btu/hr per boiler)	1,328,000	original number of boilers	8
steady state efficiency (%)	72	piping arrangement	parallel
New Boilers (Weil-McLain LGB-10W)			
input capacity (Btu/hr per boiler)	1,170,000	steady state efficiency (%)	81
Boiler Combinations			
number of new boilers and existing boilers	1 & 7	2 & 6	3 & 5

The energy use for these systems was estimated for both parallel and primary/secondary piping on the existing boilers. Weil-McLain recommended that their boilers operate with their own circulation pump, and that the boilers only be installed in a piping arrangement ("Easy-Fit") that is claimed to have very low standby losses. Under these conditions, the energy consumption estimate for the Weil-McLain boilers assumed negligible standby losses. Parallel piping was not modelled for these boilers.

Life Cycle Cost Analysis

Rather than use future projections on the consumer price index, gas price escallation rates, and the changes in interests rates, the life cycle cost analysis used actual historical escallation rates. The results were all expressed in 1988 dollars. Using these historical rates, the life cycles costs were calculated based on a 35 year period. In addition, to offset

distortions due to differing life times of the various equipment types, an annualized life cycle cost was calculated.

Results

The results of the analysis on the Weil-McLain atmospheric boilers showed that the cost savings increased with the total capacity of the new boilers. The savings were substantially increased when primary/secondary piping was used on the existing boilers. This is consistent with the results from the previous project.

The annual life cycle costs and estimated simple payback periods, for systems with payback periods of less than 5 years, are listed in the table below. (The payback period was defined as the time to recover the additional installations costs over the cost of simply substituting two of the boilers in the existing system with duplicates.)

Maximum Simple Payback: 5 years				
System			Annual Life Cycle Cost ($/yr)	Simple Payback Period (yr)
	New Boilers	Piping on Existing Boilers		
5.6	3 Weil-McLain atmospheric	primary/secondary	67,770	2.8
3.5	13 Weil-McLain high efficiency	primary/secondary	68,687	4.9
4.5	2 Weil-McLain forced draft	primary/secondary	69,113	3.6
5.5	2 Weil-McLain atmospheric	primary/secondary	69,439	1.9
4.4	1 Weil-McLain forced draft	primary/secondary	71,844	1.9
3.4	6 Weil-McLain high efficiency	primary/secondary	71,884	2.8
5.4	1 Weil-McLain atmospheric	primary/secondary	72,318	0.6
5.3	3 Weil-McLain atmospheric	parallel	72,436	3.8
1.2	baseline system	primary/secondary	73,732	1.6
5.2	2 Weil-McLain atmospheric	parallel	74,551	2.1
4.1	1 Weil-McLain forced draft	parallel	77,421	2.5
5.1	1 Weil-McLain atmospheric	parallel	77,646	0
1.1*	baseline system	parallel	78,880	-

* baseline system used in payback calculations

Recommendations

The simple payback period should not be used as the sole guideline for the selection of a new boiler system. This approach does not account for costs over the life time of the equipment. Boilers with longer payback periods may have lower life cycle costs.

The results indicate that primary/secondary piping tends to reduce both the payback period and the annual life cycles costs. Therefore, it is recommended that primary/secondary piping be used on the existing boilers.

If there are no restrictions on the initial costs of the new system, it is recommended that systems with the lowest life cycle cost be installed.

1. INTRODUCTION

There is a potential for considerable space heating energy savings, in buildings owned by the Ontario Ministry of Housing, through the installation of modern boilers with increased efficiency. Consequently, the Ministry is considering installing these new types of boilers for hydronic heating in their apartment buildings.

In a previous project done by ORTECH [1] the annual energy savings and simple payback periods were estimated for several configurations of new and existing boilers. The new boilers used in this first analysis were: HydroTherm M-150 and Weil McLain VHE-6 high efficiency boilers, and Weil McLain BG-588 W forced draft boilers.

During this investigation, it became apparent that there were other boilers that could offer significant cost savings. In particular, there are modern atmospheric boilers such as the Weil-McLain LGB-10W, that have steady state efficiencies comparable to those of forced draft boilers (~80%), and yet have a lower installed cost.

The recommendations in the previous project were based on an evaluation of payback periods. An alternative basis for selecting equipment is through a life cycle cost analysis. This approach estimates the full cost of a heating system over its entire life, whereas the payback period approach does not account for cost savings after the installed costs have been recovered.

2. OBJECTIVE AND SCOPE

The objectives of this project were:

- to estimate annual energy savings and payback periods of installing hydronic heating systems consisting of combinations of existing boilers and Weil-McLain LGB-10W atmospheric boilers. The analysis also included an evaluation of the benefits of parallel piping and primary/secondary piping.
- to estimate life cycle costs for some of the more promising configurations described in a previous project [1], and for the configurations using the boilers mentioned above;
- to provide recommendations for selecting a heating system based on the payback period and life cycle cost analysis.

3. PROCEDURE

3.1 Estimation of Energy Savings and Payback Periods for Heating Systems Utilizing Weil-McLain LGB-10W Boilers

The procedures for calculating energy savings and payback period were the same as those used in [1]. The assessment was done using ORTECH's Boiler Performance Evaluation program. This involved: selecting the specifications of hydronic heating systems for the evaluation; and calculating energy consumption and payback periods on the systems. The subsections below describe these activities.

The analysis was based on the heat loss characteristics of the building used in the previous project [1]. These characteristics are summarized in Appendix A.

Selecting Specifications of Systems for the Evaluation

The new hydronic heating systems consisted of combinations of new boilers and existing boilers. The output of the existing boilers is defined in Appendix A. The new systems are described below (the numbering system below is intended to be continuous with the numbering using in [1]):

System 5. Combinations of existing boilers, and Weil-McLain LGB-10W atmospheric boilers.

The Weil-McLain LGB-10W boilers have a steady state efficiency of about 81 % and an input capacity of about 1,170,000 Btu/hr.

The specific combinations that were analysed are iisted below:

combination	number of existing boilers	number of new atmospheric boilers
1.	7	1
2.	6	2
3.	5	3

The above arrangement was based on replacing one existing boiler with the number of high efficiency boilers that would have approximately the same total output. (1,170 x .81 ≈ 1,328 x .72) In these systems, the new boilers would be set-up as the lead boilers, so that they carry the base hydronic heating load.

The gas consumption for this system was estimated for both parallel and primary/secondary piping on the existing boilers.

Weil-McLain strongly recommends that each of their boilers operate with their own circulation pump. In addition, Weil-McLain has devised a piping arrangement ("Easy-Fit") that has very low standby losses, yet is claimed to be less costly than primary/secondary piping. Consequently, the energy consumption estimate for the Weil-McLain boilers assumed negligable standby losses. Parallel piping was not modelled for these boilers.

Calculating Energy Consumption and the Payback Period

The energy consumption of the new systems was estimated using the Boiler Evaluation Program. Using the estimated energy consumption and the installation and maintenance costs, the simple payback periods for the above described systems were calculated. The baseline for all the payback calculations was the parallel piping configuration of System 1 in [1]. (The payback period is the time to recover the additional installations costs over those of the parallel piping configuration of System 1.) In addition, the payback periods were estimated for the primary/secondary piping configuration of System 1 in [1] (6 existing boilers, 2 new conventional boilers).

3.2 Estimation of Life Cycle Costs

The life cycle cost analysis involved the following activities:

- obtaining information on the expected lifetimes of all of the boilers;
- defining future price scenarios;
- calculating the life cycle costs.

Details on the above activities are outlined below:

Expected Lifetimes of New and Existing Boilers

The lifetimes for the boilers were obtained from information in the open literature, and through discussions with manufacturers and contractors.

Price Escallation Scenario

The price escallation scenario used in this project was derived from historical price escallation data. This was done as follows:

1. The maximum of the all of the expected lifetimes of all the boilers was found. This lifetime was denoted LT_{max}.
2. The consumer price index and gas price escallation data was obtained for approximately LT_{max} years into the past from 1988.
3. The time scale correponding to this data was reset such that year 1988 - LT_{max} became year zero, and year 1988 became year LT_{max}. The price data was then normalized such that 1988 values occurred at year zero. The consumer price index was normalized such that the value one occurred at year zero (1988).

Calculating Life Cycle Costs

The life cycle cost analysis must take account of the expected life of the new boilers, the expected life of the existing boilers, and the remaining life in the existing boilers. Since each configuration consists of boilers with differing lifetimes, there is some ambiguity in defining the life cycle cost for a given configuration of boilers. This is illustrated using the equations below. The life cycle costs for the existing and new boilers in a given configuration is:

$$LCC_e = C_e P_v(LR_e) + A_e Pwef_e$$

$$LCC_n = C_n + A_n Pwef_n$$

where:

$$Pwef_e = \sum_{0}^{LTe} P_v(t)$$

= present worth escallation factor for the existing boilers

$$Pwef_n = \sum_{0}^{LTn} P_v(t)$$

= present worth escallation factor for the new boilers

LCC_e, LCC_n = life cycle cost of the existing and new boilers
C_e = cost of installing replacements for existing boilers using the same type of boilers
C_n = installed cost of the new boilers
P_v = present value factor at a given time in the future. This factor accounts for future escallations in prices, and discounting due to the time value of money.
LR_e = life remaining in the existing boiler
A_e, A_n = annual operating cost of the existing and new boilers
LT_e, LT_n = lifetime of the existing and new boilers

It should be noted that the life cycle cost for the new boiler includes the installation cost at time zero. The installation cost for the future replacement of the existing boilers will occur in the time interval between zero years and LT_e years.

Since new and existing boilers in a given system have differing lifetimes, it is not clear just how the life cycle cost for the combined system should be calculated. The approach recommended in [2] for comparing systems with differing lifetimes is to convert the life cycle costs to annualized values. The period of the annualization would correspond to the lifetime of the boiler. Using

this approach, the annualized life cycle cost for the existing and new boilers would be:

$$ALCC_e = C_e P_v(LR_e) / Pwef_e + A_e$$

$$ALCC_n = C_n / Pwef_n + A_n$$

The annualized life cycle cost for a system consisting of a mix of boilers would therefore be:

$$ALCC_{sys} = C_e P_v(LR_e) / Pwef_e + C_n / Pwef_n + A_{sys}$$

where:

$ALCC_{sys}$ = total annual life cycle cost of the system
A_{sys} = annual present operating cost of the system

4. RESULTS AND DISCUSSION

4.1 Estimation of Energy Savings and Payback Periods for Heating Systems Utilizing Weil-McLain LGB-10W Boilers

Energy Consumption

The specifications of the boilers used in the modelling are given in Table 1 (the table also shows the specifications of the other systems from [1]). The cost savings of the various systems over the baseline system are also shown in Table 1 and in Figure 1. As in the previous study, these results show that the cost savings produced by System 5 increase with the total capacity of the new boilers. The savings are substantially increased when primary/secondary piping was used on the existing boilers.

Installation and Maintenance Costs

Controls Costs for New Boilers

The cost of the control system for the Weil-McLain VHE boilers is $600 for up to 6 boilers, and $1,200 for up to 19 boilers. These prices have been included in the installation costs for these boilers.

The control system costs for the HydroPulse, Weil-McLain forced draft, and the Weil-McLain atmospheric boilers, are included in the quoted capital costs of these units. These costs have therefore been included in the installed costs.

Primary/Secondary Piping on existing Boilers

The cost information on primary/secondary piping was obtained from Fenar Group Limited.

Installed cost	$1,500	per boiler

In general, it is feasible to connect the existing Ruud boilers in a primary/secondary piping configuration.

Weil-McLain LGB-10W Boilers atmospheric boilers

The information below was obtained from D.J. Miller Sales.

input capacity	1,170,000	Btu per boiler
boiler cost including tax	$ 7130	per boiler
circulator	$ 250	per boiler
low water cut-off	$ 200	per boiler
labour	total of above costs	

The maintenance costs for the existing boilers were modified from the previous study. It was assumed that the existing boilers would have a life of 21 years, and that the refractory and heat exchanger would require replacement at year 7 and year 14. Under these assumptions, the maintenance costs per boiler would be 68$/year, and $860 (1988) at years 7 and 14.

The maintenance costs for the LGB-10W boiler were estimated from data supplied by the Ministry (fax to ORTECH on July 20, 1988, reproduced in Appendix B of [1]). These maintenance costs are summarized below:

	Annual Inspection Costs (Independent of the number of boilers) $/year	Average Annual Maintenance (Dependent on number of boilers)	$/year/boiler
Atmospheric Boiler	68	replace ignition module	25
		inspect and clean low water cut-off	11
		total	36
Primary/Secondary Piping			30

Simple Payback Periods

The simple payback periods (on the additional cost over the installation of the parallel piping version of the baseline system) are shown in Table 1 and in Figures 2 and 3. The system with the lowest payback period is System 5.1. Since the installation and annual costs of System 5.1 are less than those of the baseline system, the payback period for System 5.1 is zero years.

4.2 Estimation of Life Cycle Costs

The expected lifetimes of the various boilers are given below:

Ruud CB-1328 (copper watertube)	21 years
HydroTherm M-150 Pulse Combustion Boilers (steel fire tube)	20 - 25 years
Weil-McLain VHE-6 High Efficiency Boilers (cast iron heat exchanger)	35 years
Weil-McLain BG 588-W Forced Draft Boilers (cast iron heat exchanger)	35 years
Weil-McLain LGB-10W Atmospheric Boilers (cast iron heat exchanger)	35 years

The above lifetimes were obtained from [3] and through discussions with manufacturers. Since the maximum lifetime is 35 years, price escallation data is required for a 35 year period.

The price escallation rates used in the analysis are listed in Table 2. Gas prices were obtained directly from Consumer's Gas and were based on a rate structure that would be appropriate for apartment buildings. Since the rates in the 1960's were negotiated on an individual basis, Consumer's Gas had no formal rate structures for apartments in this period. Consequently, the rates for the 1960's were interpolated from the rates in the late 1950's and early 1970's. There were no rate structures in the early 1950's when gas was introduced into Ontario. As a result, the rates for this period were extrapolated using the rates of the late 1950's. Since the rates in the late 1950's were virtually constant, the rates used for the early 1950's were assumed to be also virtually constant.

The life cycle costs (for a study period of 35 years) and the annualized life cycle costs for all the boiler configurations are shown in Table 3. This table also shows the life cycle savings, the annualized life cycle savings and the simple payback for each of the systems. The annualized life cycle savings are graphed in Figure 4. Both the savings and the simple payback values use the parallel piping configuration of System 1 in [1] (system 1.1) as a baseline.

Using Table 3 and Figure 4 , the following observations can be made:

- In comparing the life cycle savings with the annualized life cycle savings, it can be seen that some systems have negative life cycle savings and positive annualized savings. This occurs when there are significant replacements near the end of the 35 year study period. At these conditions, replacement costs are more prominant than otherwise.

- The systems with the highest savings are the Weil-McLain boilers with primary/secondary piping. In terms of annualized savings, there is no

significant difference between the high efficiency Weil-McLain systems and the other Weil-McLain units.

- In general, the annualized savings of the HydroTherm boilers tend to be lower than those of the Weil-McLain. However, since the HydroTherm units have a shorter lifetime than the Weil-McLain units, the annualized savings calculation for the HydroTherm units included a relatively high proportion of low gas prices. If it is assumed that gas prices will increase in the near future, the predicted savings for the HydroTherm units will improve.

5. CONCLUSIONS

If the selection of the new systems is to be based on the simple payback period, the table below should be used in the selection. This table lists the systems with the lowest ten payback periods (the baseline system used in the payback calculations is included for comparison). It should be noted that the systems with the lowest payback period do not have the lowest annual life cycle cost.

System			Annual Life Cycle Cost ($/yr)	Simple Payback Period (yr)
	New Boilers	Piping on Existing Boilers		
5.1	1 Weil-McLain atmospheric	parallel	77,646	0
5.4	1 Weil-McLain atmospheric	primary/secondary	72,318	0.6
1.2	baseline system	primary/secondary	73,732	1.6
4.4	1 Weil-McLain forced draft	primary/secondary	71,844	1.9
5.5	2 Weil-McLain atmospheric	primary/secondary	69,439	1.9
5.2	2 Weil-McLain atmospheric	parallel	74,551	2.1
4.1	1 Weil-McLain forced draft	parallel	77,421	2.5
3.4	6 Weil-McLain high efficiency	primary/secondary	71,884	2.8
5.6	3 Weil-McLain atmospheric	primary/secondary	67,770	2.8
4.5	2 Weil-McLain forced draft	primary/secondary	69,113	3.6
1.1*	baseline system	parallel	78,880	-

* baseline system used in payback calculations

If the selection of the new systems is to be based on the annual life cycle cost, the table below should be used in the selection. This table lists the systems with the lowest ten life cycle costs (the baseline system used in the payback calculations is included for comparison).

System			Annual Life Cycle Cost ($/yr)	Simple Payback Period (yr)
	New Boilers	Piping on Existing Boilers		
3.6	19 Weil-McLain high efficiency	primary/secondary	67,414	6.4
5.6	3 Weil-McLain atmospheric	primary/secondary	67,770	2.8
4.6	3 Weil-McLain forced draft	primary/secondary	68,132	5.1
3.5	13 Weil-McLain high efficiency	primary/secondary	68,687	4.9
4.5	2 Weil-McLain forced draft	primary/secondary	69,113	3.6
5.5	2 Weil-McLain atmospheric	primary/secondary	69,439	1.9
4.4	1 Weil-McLain forced draft	primary/secondary	71,844	1.9
3.4	6 Weil-McLain high efficiency	primary/secondary	71,884	2.8
3.3	19 Weil-McLain high efficiency	parallel	72,091	9.1
5.4	1 Weil-McLain atmospheric	primary/secondary	72,318	0.6
1.1*	baseline system	parallel	78,880	-

* baseline system used in payback calculations

6. RECOMMENDATIONS

1. The results indicate that primary/secondary piping reduces both the payback period and the annualized life cycles costs. Therefore, it is recommended that primary/secondary piping be used on the existing boilers.

2. The simple payback period should not be used as the sole guideline for the selection of a new boiler system. This approach does not account for costs over the lifetime of the boiler. Boilers with longer payback periods may have lower life cycle costs.

3. If there are no restrictions on the initial costs of the new system, it is recommended that systems with the lowest life cycle cost be installed.

4. If there are restrictions on the initial costs, it is recommended that the selection be guided by both the life cycle costs and the payback periods. If the maximum allowable payback period is 2 years, the systems listed below are recommended (in order of increasing life cycle cost).

Maximum Simple Payback: 2 years				
System			Annual Life Cycle Cost ($/yr)	Simple Payback Period (yr)
	New Boilers	Piping on Existing Boilers		
5.5	2 Weil-McLain atmospheric	primary/secondary	69,439	1.9
4.4	1 Weil-McLain forced draft	primary/secondary	71,844	1.9
5.4	1 Weil-McLain atmospheric	primary/secondary	72,318	0.6
1.2	baseline system	primary/secondary	73,732	1.6
5.1	1 Weil-McLain atmospheric	parallel	77,646	0
1.1*	baseline system	parallel	78,880	-

* baseline system used in payback calculations

If the maximum allowable payback period is 5 years, the systems listed below are recommended.

Maximum Simple Payback: 5 years				
System			Annual Life Cycle Cost ($/yr)	Simple Payback Period (yr)
	New Boilers	Piping on Existing Boilers		
5.6	3 Weil-McLain atmospheric	primary/secondary	67,770	2.8
3.5	13 Weil-McLain high efficiency	primary/secondary	68,687	4.9
4.5	2 Weil-McLain forced draft	primary/secondary	69,113	3.6
5.5	2 Weil-McLain atmospheric	primary/secondary	69,439	1.9
4.4	1 Weil-McLain forced draft	primary/secondary	71,844	1.9
3.4	6 Weil-McLain high efficiency	primary/secondary	71,884	2.8
5.4	1 Weil-McLain atmospheric	primary/secondary	72,318	0.6
5.3	3 Weil-McLain atmospheric	parallel	72,436	3.8
1.2	baseline system	primary/secondary	73,732	1.6
5.2	2 Weil-McLain atmospheric	parallel	74,551	2.1
4.1	1 Weil-McLain forced draft	parallel	77,421	2.5
5.1	1 Weil-McLain atmospheric	parallel	77,646	0
1.1*	baseline system	parallel	78,880	-

* baseline system used in payback calculations

7. RECOMMENDED FUTURE WORK

The life cycle cost analysis that was performed in this project was based on historic price escallation and interest rates. An alternative approach would be to perform this analysis using future projections on these rates. Since this approach is more consistent with standard practice for life cycle costing, the results from such an analysis could be compared to other life cycle cost studies.

Several price scenarios could be selected for the life cycle cost analysis. This multiple scenario approach could be used to indicate the sensitivity of the life cycle costs to changes in future prices and interest rates.

HydroTherm has just reduced the installed cost of their M-300 (300,000 Btu/h) high efficiency boiler to $10,000. This change may produce payback periods that are comparable to those of the Weil-McLain high efficiency boilers. Therefore, the payback and life cycle cost analysis should be undertaken for the HydroTherm M-300 boilers.

[1] ORTECH Corporation, "High Efficiency Boiler Evaluation for the Ontario Ministry of Housing, Case Building: 5 Bellevue Crescent, Toronto", 35-22095, September 1988

[2] Ruegg R.T., McConnaughey J.S., Sav G.T., Hockenbery K.A., "Life-Cycle Costing, A Guide for Selecting Energy Conservation Projects for Public Buildings", prepared for the US Department of Energy by the National Bureau of Standards, Report NBS BSS-113, September 1978, pp 6

[3] ASHRAE 1987 HVAC Handbook pp 49.7

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APPENDIX A: HEAT LOSS CHARACTERISTICS OF THE BUILDING

The building used in the analysis is an apartment building at 5 Bellevue Crescent, Toronto, owned by the Ontario Ministry of Housing. This building is a 21 storey building with 326 suites.

Energy consumptions from gas bills have been entered into the Boiler Evaluation Program for the previous project [1]. Using regression analysis, the program estimated the hydronic heating load as a function of outdoor temperature. This calculation included an estimate of the standard deviation of the heating load as a function of outdoor temperature (due to scatter in data points and uncertainty in efficiency).

The analysis was based on the following assumptions:

- The current heating plant has 8 boilers at 1,328,000 Btu/h input each, and 72 % steady state efficiency. The part-load characteristics of these boilers were assumed to be such that the seasonal efficiency of the existing heating system is 65 %.

- The gas use for domestic hot water was taken from OHC's energy consumption field report ("gas-hot water" component). The DHW gas use figures for the above two year period were averaged and entered into the calculations.

- The model for the corridor heating assumed that:
  - The heater's on-time was no more than 33 %.
  - The heater was not activated at all between June 1 and September 15.
  - The gas consumption of the corridor heater was equal to about 8 % of the total annual gas consumption.
  - When the heater was cycling, its cycling rate was directly proportional to the temperature difference between its set point (72 °F) and the outdoor temperature.

TABLE 1 SUMMARY OF RESULTS FOR BOILER EVALUATION
5 Bellevue Crescent, Toronto

		Original System	Baseline System		New Boilers: HydroPulse M-150						New Boilers: Weil-McLain VHE-6					
			parallel	prim/sec	parallel on old boilers			prim/sec on old boilers			parallel on old boilers			prim/sec on old boilers		
System Number		0	1.1	1.2	2.1	2.2	2.3	2.4	2.5	2.6	3.1	3.2	3.3	3.4	3.5	3.6
Existing Boilers																
Steady State Efficiency		0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Input Capacity per Boiler	Btu/hx1E3	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328
Number of Boilers		6	6	6	7	6	5	7	6	5	7	6	5	7	6	5
New Boilers																
Steady State Efficiency		0.72	0.75	0.75	0.906	0.906	0.906	0.906	0.906	0.906	0.874	0.874	0.874	0.874	0.874	0.874
Input Capacity per Boiler	Btu/hx1E3	1,328	1,328	1,328	150	150	150	150	150	150	167	167	167	167	167	167
Number of Boilers		2	2	2	7	14	21	7	14	21	6	13	19	6	13	19
Expected Lifetime	years	20	20	20	23	23	23	23	23	23	35	35	35	35	35	35
Seasonal Efficiency		0.653	0.676	0.737	0.715	0.771	0.810	0.784	0.847	0.885	0.703	0.754	0.787	0.768	0.826	0.857
Energy Use	Btu/yx1E6	16,349	15,785	14,481	14,924	13,841	13,188	13,620	12,606	12,068	15,196	14,162	13,574	13,892	12,926	12,454
Annual Costs																
Energy	$/yr	75,150	72,550	66,560	68,600	63,620	60,620	62,600	57,940	55,470	69,850	65,090	62,390	63,850	59,410	57,240
Maintenance	$/yr	1,050	1,050	1,290	1,980	2,850	3,710	2,190	3,030	3,860	1,350	1,640	1,870	1,560	1,820	2,020
Total	$/yr	76,200	73,600	67,850	70,580	66,470	64,330	64,800	60,970	59,330	71,200	66,730	64,260	65,410	61,230	59,260
Savings Compared to Baseline																
	$/yr	-2,590	0	5,750	3,030	7,140	9,280	8,810	12,640	14,280	2,410	6,870	9,340	8,190	12,370	14,340
uncertainty	$/yr	-240	0	540	1,010	1,290	1,340	1,070	1,190	1,250	800	1,240	1,340	990	1,170	1,260
Installation Costs	$		21,200	30,200	59,500	119,000	178,500	70,000	128,000	186,000	33,960	73,380	106,140	44,460	82,380	113,640
uncertainty			2,120	3,020	5,950	11,900	17,850	7,000	12,800	18,600	3,400	7,340	10,610	4,450	8,240	11,360
Simple Payback*	yr			1.6	12.6	13.7	17.0	5.5	8.4	11.5	5.3	7.6	9.1	2.8	4.9	6.4
uncertainty	yr			0.2	4.4	2.8	3.0	0.9	1.2	1.5	1.8	1.6	1.6	0.4	0.7	0.9

* on additional installation costs over baseline

TABLE 1 continued

		New Boilers: Weil-McLain BG 588-W forced draft						New Boilers: Weil-McLain LGB-10W atmospheric					
		parallel on old boilers			prim/sec on old boilers			parallel on old boilers			prim/sec on old boilers		
System Number		4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2	5.3	5.4	5.5	5.6
Existing Boilers													
Steady State Efficiency		0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Input Capacity per Boiler	Btu/hx1E3	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328	1,328
Number of Boilers		7	6	5	7	6	5	7	6	5	7	6	5
New Boilers													
Steady State Efficiency		0.82	0.82	0.82	0.82	0.82	0.82	0.81	0.81	0.81	0.81	0.81	0.81
Input Capacity per Boiler	Btu/hx1E3	1,397	1,397	1,397	1,397	1,397	1,397	1,170	1,170	1,170	1,170	1,170	1,170
Number of Boilers		1	2	3	1	2	3	1	2	3	1	2	3
Expected Lifetime	years	35	35	35	35	35	35	35	35	35	35	35	35
Seasonal Efficiency		0.694	0.729	0.750	0.761	0.799	0.816	0.685	0.716	0.737	0.749	0.782	0.801
Energy Use	Btu/yx1E6	15,380	14,650	14,235	14,022	13,360	13,081	15,549	14,894	14,452	14,245	13,658	13,334
Annual Costs													
Energy	$/yr	70,690	67,340	65,430	64,450	61,410	60,120	71,470	68,460	66,430	65,480	62,780	61,290
Maintenance	$/yr	1,060	1,010	950	1,270	1,190	1,100	970	880	790	1,180	1,060	940
Total	$/yr	71,750	68,340	66,380	65,720	62,600	61,220	72,440	69,340	67,220	66,650	63,840	62,230
Savings Compared to Baseline													
	$/yr	1,850	5,260	7,230	7,880	11,010	12,380	1,170	4,270	6,390	6,950	9,770	11,380
uncertainty	$/yr	620	950	1,040	960	1,040	1,090	390	770	920	840	920	1,000
Installation Costs	$	25,800	51,600	77,400	36,300	60,600	84,900	15,160	30,320	45,480	25,660	39,320	52,980
uncertainty		2,580	5,160	7,740	3,630	6,060	8,490	1,520	3,030	4,550	2,570	3,930	5,300
Simple Payback*	yr	2.5	5.8	7.8	1.9	3.6	5.1	0.0	2.1	3.8	0.6	1.9	2.8
uncertainty	yr	0.9	1.2	1.4	0.3	0.5	0.7	0.0	0.4	0.7	0.1	0.3	0.4

* on additional installation costs over baseline

TABLE 2: PRICE ESCALLATION AND INTEREST RATE DATA

Year	Consumer Price Index (1981 = 100)	Annual Inflation Rate at Year End	Gas Price Index (1981 = 100)	Gas Escalation Rate	Treasury Bill Interest Rates
		%		%	%
1953	28.3	-0.70	37.8	0.00	1.71
1954	28.4	0.35	37.8	0.00	1.43
1955	28.5	0.35	37.8	0.00	1.62
1956	28.9	1.40	37.8	0.00	2.93
1957	29.8	3.11	37.8	0.00	3.76
1958	30.6	2.68	37.8	0.00	2.25
1959	31.0	1.31	37.8	0.00	4.81
1960	31.4	1.29	37.5	-0.79	3.20
1961	31.7	0.96	36.9	-1.60	2.81
1962	32.0	0.95	36.6	-0.81	4.05
1963	32.6	1.88	35.6	-2.73	3.56
1964	33.2	1.84	34.7	-2.53	3.75
1965	34.0	2.41	33.6	-3.17	3.98
1966	35.2	3.53	32.5	-3.27	5.00
1967	36.5	3.69	31.6	-2.77	4.64
1968	38.0	4.11	30.5	-3.48	6.27
1969	39.7	4.47	29.4	-3.61	7.19
1970	41.0	3.27	28.9	-1.70	5.99
1971	42.2	2.93	28.8	-0.35	3.56
1972	44.2	4.74	28.8	0.00	3.56
1973	47.6	7.69	29.1	1.04	5.47
1974	52.8	10.92	31.6	8.59	7.82
1975	58.5	10.80	41.6	31.65	7.40
1976	62.9	7.52	56.9	36.78	8.87
1977	67.9	7.95	60.0	5.45	7.33
1978	73.9	8.84	70.3	17.17	8.68
1979	80.7	9.20	75.3	7.11	11.69
1980	88.9	10.16	81.9	8.76	12.79
1981	100.0	12.49	100.0	22.10	17.72
1982	110.8	10.80	130.0	30.00	13.66
1983	117.2	5.78	151.9	16.85	9.06
1984	122.3	4.35	153.1	0.79	11.06
1985	127.2	4.01	151.6	-0.98	9.43
1986	132.4	4.09	148.3	-2.18	9.00
1987	138.2	4.38	142.2	-4.11	8.14
1988	143.9	4.10	141.3	-0.63	9.43

TABLE 3: LIFE CYCLE COSTS FOR VARIOUS CONFIGURATIONS OF BOILERS

System Number	Life Cycle Cost 35 yr Period 1988 $	Annualized Life Cycle Cost 1988 $	Savings Based on System 1.1		Simple Payback Period years
			Life Cycle Savings 35 yr Period 1988 $	Annualized Life Cycle Savings 1988 $	
0	1,841,420	81,410	-73,750	-2,530	-
1.1	1,767,670	78,880	0	0	-
1.2	1,650,670	73,730	117,010	5,150	1.6
2.1	1,815,650	78,860	-47,970	20	12.6
2.2	1,822,780	77,810	-55,100	1,070	13.7
2.3	1,873,870	78,740	-106,200	140	17.0
2.4	1,708,010	73,720	59,670	5,160	5.5
2.5	1,718,590	72,870	49,080	6,010	8.4
2.6	1,777,800	74,210	-10,120	4,670	11.5
3.1	1,748,610	77,220	19,060	1,660	5.3
3.2	1,673,010	73,800	94,660	5,080	7.6
3.3	1,634,780	72,090	132,900	6,790	9.1
3.4	1,632,000	71,880	135,670	7,000	2.8
3.5	1,561,140	68,690	206,530	10,190	4.9
3.6	1,532,300	67,410	235,380	11,470	6.4
4.1	1,750,710	77,420	16,960	1,460	2.5
4.2	1,682,700	74,480	84,980	4,410	5.8
4.3	1,646,650	72,970	121,020	5,910	7.8
4.4	1,628,780	71,840	138,900	7,040	1.9
4.5	1,565,270	69,110	202,400	9,770	3.6
4.6	1,540,620	68,130	227,050	10,750	5.1
5.1	1,754,570	77,650	13,110	1,230	0.0
5.2	1,682,590	74,550	85,090	4,330	2.1
5.3	1,632,370	72,440	135,310	6,440	3.8
5.4	1,638,180	72,320	129,490	6,560	0.6
5.5	1,570,710	69,440	196,960	9,440	1.9
5.6	1,530,110	67,770	237,570	11,110	2.8

Figure 1: Cost Savings Over Baseline (System 1.1)

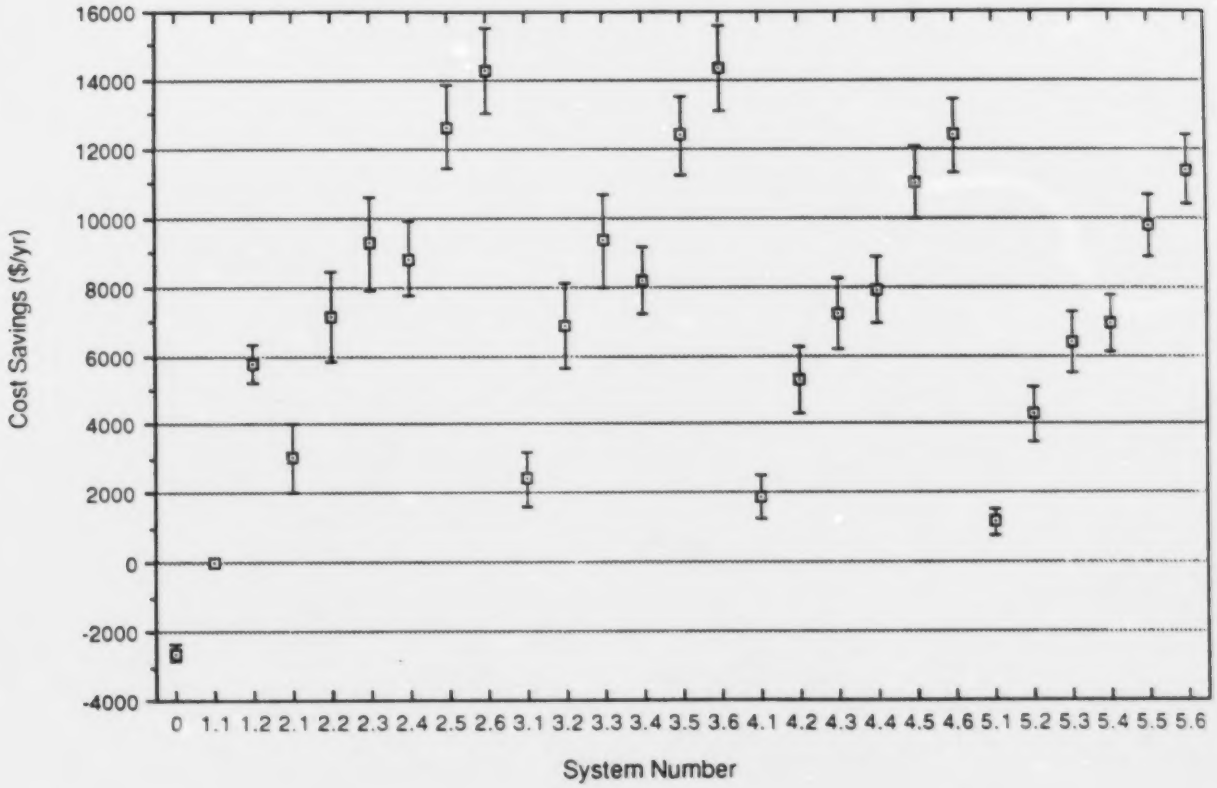

Figure 2: Payback Period on Additional Costs Over Baseline (System 1.1)

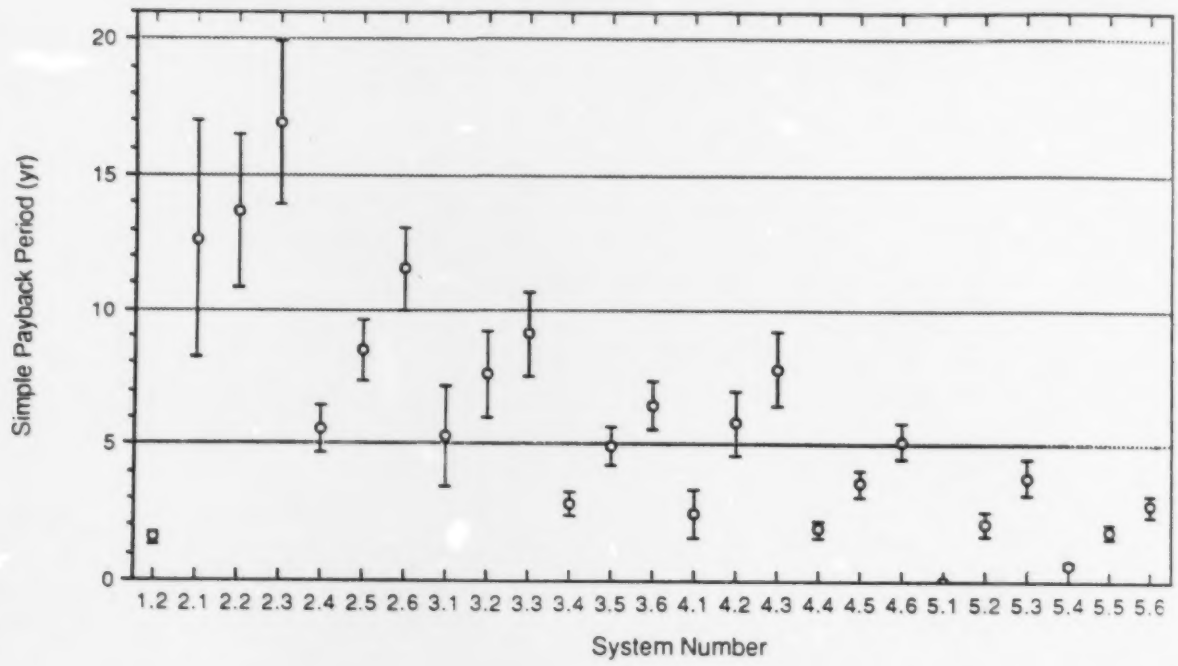

Figure 3: Payback Period on Additional Costs Over Baseline (System 1.1) Lower Payback Periods

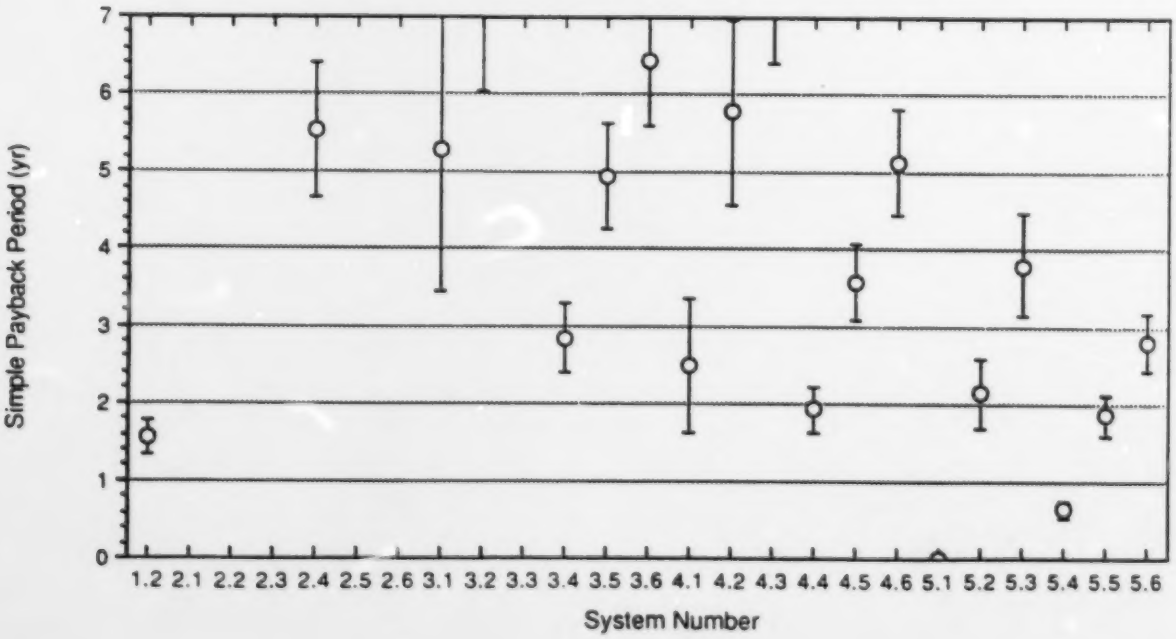

Figure 4: Annualized Life Cycle Savings Over Baseline (System 1.1)